the ATHENA™ *Sustainable Materials Institute*

US LCI DATABASE PROJECT
RESEARCH PROTOCOL

Final Phase I Version

Prepared for:

National Renewable Energy Laboratory

By:

ATHENA™ Sustainable Materials Institute

In association with:

Franklin Associates, Ltd.

and

Sylvatica

January, 2002

ACKNOWLEDGMENTS

We would like to acknowledge the funding provided by the US Department of Energy, the General Services Administration, and the Naval Facilities Engineering Command, which made this project possible. We also want to acknowledge the valuable contributions of the many volunteers who worked with us as part of the project advisory group, all of whom are listed on the project web site and in the final Phase I project report, and to thank Paul Torcellini and Michael Deru of the National Renewable Energy Laboratory for their advice, forbearance and support throughout the project. Finally, we thank Dr. Patrick Hofstetter, who chaired the critical review team comprising Gregory Keoleian at the University of Michigan, John Sullivan at Ford Motor Company, and Keith Weitz at Research Triangle Institute. All gave freely of their time and provided a detailed and highly constructive review report with specific recommendations that have vastly improved this protocol.

CONTENTS

US LCI DATABASE PROJECT RESEARCH PROTOCOL

Final Phase I Version

1 INTRODUCTION

This protocol is intended as a guide for the development of life cycle inventory (LCI) data during Phase II of the US Database Project.

The ultimate objective of the project is to develop publicly available LCI data modules for commonly used materials, products and processes. The purpose is threefold: to support public, private, and non-profit sector efforts to develop product life cycle assessments (LCAs) and LCA-based decision support systems and tools; to provide regional benchmark data for generating or assessing company, plant or new technology data; and to provide a firm foundation and broad data resource base for conducting LCAs generally.

The project is intended to support the growing trend of taking a systems view when evaluating the environmental performance of products and services. However, tradeoffs are often encountered in systems analyses, and database users might find it appropriate to choose a subsystem or material that carries higher environmental burdens over alternatives because it imparts an overall environmental performance improvement to the product system under study. Providing sufficiently reliable information to assess system environmental performance in the light of tradeoffs is one of the prime reasons for developing such a database.

As discussed in the following section on goal and scope definition, the US database project differs from typical life cycle assessments of individual products, processes or systems. Those differences affect this document in certain fundamental ways that are made clear in various sections of the protocol. We especially have to anticipate a much broader range of potential uses and users of the LCI data, with attendant variety in the manner in which, and degree to which, the LCI data will be used for full LCA purposes.

This protocol document is intended for the use of LCA practitioners or others who will be directly involved in development of the LCI data modules, and for interested observers/reviewers of the project. As a result, we have assumed a basic level of understanding about LCA principles and practices, including the ISO 14000 series of standards and technical reports, and have not attempted to explain or justify all of the procedures or guidelines.

The protocol has been prepared as part of a broader Phase I work programming effort. The companion Phase II Work Program document provides a list of the processes recommended for study in Phase II, in priority order, as well as an overview discussion of current data availability from the perspective of this project and recommendations for further work that will augment or supplement this protocol. In fact, as explained in that report, the protocol itself is a work in progress. This final Phase I Version has been modified to account for some, but not all, of the comments received as a result of the formal review process. Further modification is expected early in Phase II, but the protocol should continue to evolve as the science evolves and as lessons are learned during its application.

An important task recommended in the Phase II Work Program is the development of a detailed data user's guide that will explain how modules can be used in full LCAs (see Section 2, below, for a description of the module concept). The user's guide will contain example process trees and clear guidelines to ensure, to the extent possible, that data users take full account of relevant environmental effects without double counting, including during the use phase of products. The user's guide will be particularly important with regard to such difficult LCA steps as co-product allocation and accounting for material recycling and reuse (Sections 14 and 15 of this protocol).

2 GOAL AND SCOPE DEFINITION

2.1 Project Goal

The basic goal of Phase II of the database project is to establish and maintain LCI modules that can be readily accessed, combined and augmented to develop more complex LCIs or full LCAs.

The goal is not to carry out full product LCIs in this project, but rather to make the creation of such LCIs easier, while reducing the problem of data inconsistency and incompatibility that currently plagues the LCA field in general. Accordingly, database modules will provide data on many of the processes needed to conduct life cycle analyses, but will not contain data characterizing the full life cycles of specific products. For example, LCI data on electricity generation, transportation fuel use and emissions, and energy production and pre-combustion is required for virtually all LCAs, and will be provided as a series of modules. Other modules could include mining and quarrying activities, commodity metals production, the production of basic building block petrochemicals, etc. Data documentation released by the project must make the above goal clear.

It is also important to carefully distinguish the concept of <u>publicly available data</u> from the idea of data <u>for use by the general public</u>. While the data modules developed through this project will be made publicly available, they will not be intended for use by the general public in the way that full product LCIs might be used. The modules will typically be used in combination with each other, and with other data to be developed or provided by data users.

It is expected that users of the database are likely to include the following groups:

- manufacturers, researchers, policy analysts, and others undertaking LCAs of specific products or processes;
- developers and users of tools for LCA practitioners;
- developers of tools for non-practitioners, which typically do not allow the user to modify embedded databases; and

- organizations or individuals engaged in product assessment and labeling at various levels of system complexity, from relatively simple consumer products to complex systems like buildings and automobiles.

Two common threads run through this list:

1. an assumed level of knowledge and sophistication on the part of the anticipated users, and
2. the fact that the database will provide a resource base for LCAs, rather than presenting completed cradle-to-grave LCA comparisons of individual product life cycles.

It is important to recognize that point 2, above, dictates adoption of the highest feasible data development standards. Since we do not know in advance precisely how or why individual database modules will be used, this protocol assumes the most stringent requirements in terms of data categories, transparency, review and other factors that are normally determined by the starting goal and scope statement of a study as described in ISO 14041. In general, that means assuming the data will be used in full LCAs for the purpose of making public comparative assertions.

A critical proviso with regard to the use of the database modules is that they will be developed principally for use in "attributional" LCAs, which seek to establish the burdens associated with the production and use of a product, or with a specific service or process, at a point in time (typically in the recent past). The modules will not be developed at the outset to serve the needs of those undertaking "consequential" LCAs, which seek to identify the environmental consequences of a decision or a proposed change in a system under study. Consequential LCAs can impose different requirements from an LCI perspective (e.g., marginal electricity generation may be more appropriate for a consequential LCA than average generation), and it is not clear at this point that the data modules can be developed to serve both needs equally well. We have therefore opted to focus first on the needs of attributional studies, leaving the data requirements of consequential studies for future assessment as the database evolves.

2.2 Compliance with ISO 14041

This project intends to develop a database of LCI data modules that are compliant with ISO 14041, and that help users conduct full LCAs that are ISO 14041-compliant. If for any reason a study module cannot adhere to a relevant requirement of ISO 14041, it will be incumbent on the analysts first to obtain agreement from the project managers for any departure and then to fully explain the departure, at least indicating the directional effect(s) on the relevant unit processes.

Other aspects of the project scope are covered in the following sections of this protocol.

3 BOUNDARIES

3.1 General Description

Production systems generally consist of a combination of unit processes (see Section 4 for a discussion of unit process definition). In a full product LCI or LCA, the entire system must be limited by an imaginary boundary that encompasses the full life cycle and all of the essential operations for which information will be collected.

This project, in contrast, will be providing basic LCI data modules covering some, but not necessarily all, of the unit processes contained within the boundary of a full product LCI or LCA. The boundaries for each production module under study in this project will therefore be separately and more narrowly determined on a case-by-case basis, with some modules covering cradle-to-gate and some gate-to-gate processes. For example, a module could be defined to include just the extraction and crushing of limestone with boundaries that stop at the quarry or crushing facility gate. Any more elaborate process that requires limestone, like cement manufacturing, could then call on that module and incorporate the LCI data for this common unit process.

By combining appropriate modules, it will be possible to construct the cradle-to-gate systems necessary to reach pre-defined levels of production for materials or products that have been studied. The pre-defined level may in some cases be an intermediate product such as steel reinforcing bar, and in other cases a final product like softwood lumber.

Boundaries will also have to be established for generic transformation unit processes included in the project. Transformations are defined as typical manufacturing, finishing or end-of-life processes (e.g. extruding, stamping, painting, shredding and baling, and incineration) that would be applicable to a wide range of full LCI/LCA studies of specific products. This project will not include use and maintenance phase activities other than those that might be covered by transformation modules as defined above.

3.2 Specific Boundaries

Data and estimates must be based on relevant, practical and appropriate analysis boundaries. The boundaries may include such activities as the following:

- acquisition, beneficiation, storage and transfer of raw materials, including construction and earth-moving which must be done to gain access to a raw material, and non-point emissions from these operations;
- acquisition, storage and transfer of energy which will be calculated from a set of standard processes unless specific data is available for a unit process;
- processing of raw materials into primary products (e.g. steel, rolls of paperboard);
- transformation of primary products into secondary products (e.g. steel joists, corrugated boxes);
- disposal, incineration, recovery of waste materials, and recycling and other end of life unit processes;
- transportation of materials, fuels and products at all stages; and
- allocated energy requirements of, and waste accumulation from, pollution control processes that are not an integral part of the industrial processes under study (e.g. a central waste water treatment plant).

The boundaries will not typically include the following activities, depending on relative environmental significance per unit of production (see Sections 6 and 7):

- construction of plants, vehicles or other machinery used for any phase of production;
- maintenance and administration of plants or equipment; and
- transportation of people to work and related infrastructure costs.

One of the recommended Phase II tasks is the development of tests for relevance that can be made available as an annex to the protocol. In the absence of such tests, the preceding items can be excluded with the proviso that datasets may require subsequent modification to add missing elements found to be more important than previously thought.

3.3 Non-Domestic Production

Researchers will not be required to trace with primary data the full energy and environmental costs of non-domestic production of raw resources or components to the countries of origin. If data are available for non-domestic processes for the region of interest, it will be used with appropriate citations. In cases where region-appropriate LCI data for non-domestic processes are unavailable from both primary and secondary sources, the supply chain will be modeled using process data characterizing US production technologies. These data should then be adapted where possible by using available information to characterize key aspects of the non-domestic supply chain, such as transportation distances, and fuels used to generate electricity.

Transportation energy and associated emissions will be included for imports based on the actual location of production, hauling distances and typical modes of transportation.

4 UNIT PROCESS DATA DEVELOPMENT

Descriptions of industrial processes can be obtained and aggregated at different levels of complexity and extent. ISO (14040) defines a unit process as the “smallest portion of a product system for which data are collected when performing a life cycle assessment.” Thus, if data (on inventory flows, product flows, and inputs from other processes) are collected at the level of a stamping press, then the stamping press is by definition a unit process. If the same sorts of data are collected at the level of entire factories, the factory level is then defined as a unit process. A model of an entire supply chain will generally contain data for unit processes at various physical scales.

For this project, the goal is to obtain data for unit process modules that represent sub-sets of an industry so that users of the data can understand and combine various components of a product system, and so that critical reviewers can conduct technical analyses. Higher levels of aggregation of data (i.e., defining a unit process to include more activities) will result in a loss of information, reduce the level of transparency, and inhibit critical review.

In addition, some components of a product system, such as limestone quarrying, are used in many applications. Defining that type of activity as a separate unit process will eliminate the need to conduct multiple procurements of the same data, and prove useful to users constructing many different LCI models.

5 DATA TYPES

5.1 Primary vs. Secondary

There are numerous types of data that can be acquired for conducting LCI studies, and it is important to distinguish between primary and secondary data.

Primary data are those obtained from specific facilities.

Secondary data are those included in the product system life cycle inventory that have been obtained from published sources. Examples of secondary data sources include published literature, other LCI studies, emissions permits, and general government statistics (e.g., mineral industry surveys, Bureau of Labor statistics, and Energy Information Administration data).

All data should be identified as being either primary or secondary as part of routine data documentation. The most representative and reliable data should always be used, with the proviso that critical reviewers should be able to verify that the data is current and reasonably represents relevant aspects of the unit process under study (see Section 12, Transparency).

5.2 Units

All data should be presented in metric (SI) units. Where conversions are required from imperial or US units, the conversion factors provided in Appendix A must be used and the conversion must be clearly identified in the data documentation.

5.3 Technology

The intent is to develop industry average data for the range of technologies currently in use for specific unit processes. If more than one technology is used in an industry, data should be collected for the full technology range and then aggregated to produce weighted averages, with the relative contribution to the market by each technology type used as the weights (see also Section 13). Data by technology type should also be separately reported unless confidentiality agreements with manufacturers prevent its disclosure.

6 ELEMENTARY FLOWS

The TRACI (Tool for Reduction and Assessment of Chemical Impacts), under development by the US EPA, will be used in conjunction with other impact assessment methods to determine impact assessment data requirements. The elementary flows (environmental interventions) to be tracked will, to the extent possible or practical, be those required to support characterization measures in systems such as TRACI.

While it is important to gather all reasonably available resource use and emission data and not unduly restrict data collection efforts, it is also important to balance often conflicting criteria of practicality and comprehensiveness. For example, characterization measures concerning land use in TRACI and other methodologies have not yet been developed to a level that would deem them to be “generally accepted”. The significant data requirements of those measures are therefore considered of lower priority in this project, with a higher priority given to data required to calculate global warming, acidification, eutrophication, photochemical ozone creation, and ozone depletion measures. In addition, any data should be reported that is required to be collected by regulatory agencies and is available at a unit process level (e.g., EPA criteria air pollutants and Toxic Release Inventory data).

Data collection should also include all significant raw resource requirements and solid wastes, categorized as either hazardous or non-hazardous.

Prior to Phase II data collection, an annex to this protocol will be issued with substance nomenclature and other specific data reporting guidelines.

7 EXCLUSION OF SMALL AMOUNTS

Within the defined boundary of a process, the level of detail of the analysis should be sufficient to reveal all significant environmental effects. Effort need not be spent on developing data for materials of negligible significance.

The decision rules for this project are as follows:

- include all material inputs that have a cumulative total of at least 95% of the inputs to the unit process, by mass;
- include all material inputs that have a cumulative total of at least 95% of total energy inputs to the unit process; and
- include any material, no matter how small its mass or energy contribution, that has significant effects in its extraction, manufacture, use or disposal, is highly toxic, or is classed as hazardous waste.

The above percentages are intended as guides, with analysts expected to document procedures and decisions as per the requirements of Section 12, including the justification for deviations from the above guides.

8 CARBON CYCLE

The CO2 emissions generated by a system under study must be documented, and several relevant aspects of the carbon cycle must be distinguished:

- sequestration of carbon in biomass;
- emissions from combustion of fossil and biomass fuels;
- process emissions (e.g., decomposition of carbonate in a cement kiln);
- emissions from landfills or other end-of-life processes; and
- re-carbonization of products originally containing carbonates, such as concrete or limestone products.

Emissions from the combustion of fossil fuels will be captured in common energy combustion modules (see Section 10). In the case of biomass fuels, CO2 emissions should be separately identified so that users of the data modules can readily determine whether to include or exclude the emissions in characterization measures.

Where data availability permits, unit process data should also explicitly report sequestration of CO2 where relevant, so that users of the data will be able to identify the net flux of CO2 to the atmosphere resulting from the entire sequence of unit processes in a given life cycle.

In the case of end-of-life unit process modules, carbon releases (or expected carbon releases), including releases in the form of methane, should be separately identified to the extent possible, with full documentation of any calculations or other rationale underlying estimates of expected releases.

Re-carbonization of concrete or other products originally containing carbonates is essentially a use-phase effect that will normally be outside the scope of analysis for LCI modules developed in this project. However, care must be taken in data presentation to alert data users to take account of re-carbonization as appropriate (i.e., by clearly noting that it has not yet been accounted for in process modules).

9 ENERGY RESOURCES USED AS MATERIAL INPUTS

The energy value of fossil fuels used as material feedstocks will be included in the energy requirements for a unit process as if those fossil fuels were burned as fuels. For example, hydrocarbons that are used to manufacture plastics will have an energy value (often termed “inherent energy” or “feedstock energy”) reported even though they are not burned. These values will be clearly marked and reported separately from energy derived from fuel combustion, and will also be added as part of aggregate energy use for a unit process.

The inherent or feedstock energy of biomass feedstocks will not be included in aggregate energy use for a unit process because biomass is not currently a significant source of energy in the United States. For example, paper products are not derived from logs intended to be used for direct combustion to produce energy, nor would the logs be harvested for that purpose.

However, biomass such as the logs used for paper production may in the future account for a larger percentage of the fuel supply through conversion processes, to ethanol for example. As this practice becomes more significant, feedstock energy values may have to be attributed as for fossil fuels, and this protocol revised accordingly. The fact that the quantities of biomass used as material inputs will have been tracked in LCI modules will make it possible to revise the calculations in the future to include the appropriate feedstock energy values if warranted. Where there is any question or doubt as to whether a specific feedstock should be considered as a significant energy resource, the corresponding feedstock values will be assigned and separately reported, but not included in aggregated energy totals.

To the extent that biomass is burned for energy in a manufacturing process, that energy will be reported as biomass energy and will be included in aggregated energy totals.

10 COMMON ENERGY AND TRANSPORTATION MODULES

As discussed in the final Phase II work program planning report, the US LCI database project will include separate data modules for common electricity generation, energy combustion, energy pre-combustion and transportation processes applicable to virtually all LCAs. It is therefore critical that all other unit process modules avoid double counting by doing the following:

1. record electricity use in kilowatt hours and voltage (if available) at the point of use (i.e., with no adjustments for line losses), rather than in estimated amounts of primary energy used to generate electricity;
2. record energy use by fuel and equipment type (e.g., natural gas turbine), but not combustion emissions or pre-combustion effects unless there is data available that is specific to that unit process, in which case it must be clearly described; and
3. record tonne-kilometers of transportation by mode at all process stages, and identify if empty backhauls are typical for specific transportation links (e.g., hauling of aggregates from quarries), but not the actual energy use or effects of combustion.

The common energy and transportation modules will include at least the following:

- process and transportation energy and process emissions for the production and processing of fuels including coal, natural gas, fuel oil (distillate and residual), gasoline, liquefied petroleum gas (LPG), fuel grade uranium, and emerging energy sources;
- total pre-combustion fuel use and fuel-related emissions for the production of the above fuels;
- pre-combustion and combustion energy factors for fuels (energy units per physical fuel unit);
- energy consumption for the generation and delivery of one composite Kilowatt-Hour of electricity for US national and regional grids (pre-combustion and combustion energy in both fuel and energy units);
- transportation fuel requirements (in fuel units and energy per tonne-kilometer for various transportation modes, including pre-combustion and combustion energy); and
- environmental emissions (pre-combustion and combustion) per 1,000 fuel units for the combustion of fuels used in the following:
    - industrial and utility boilers
    - industrial equipment
    - various modes of transportation, including
        i. tractor-trailer trucks
        ii. single unit trucks
        iii. locomotives
        iv. barges
        v. ocean freighters
        vi. air cargo.

Users of the database modules will have to be advised that the electricity grids used in an LCI should match the LCI's functional unit and boundaries: where unit process data are available on a regional basis, regional grids should be used; where unit process data cannot be related to specific regions, the national grid should be used; and, in situations where electricity is an especially important issue and plant locations are dictated by sources of electricity (e.g., electro-process industries), specific industry data should be used. Both national and regional electricity grids will be included in the electricity, fuels and energy database.

Note that fuel use for self-generated electricity should be included in the process energy reported for a unit process.

11 DATA FORMAT AND COMMUNICATION

The central data access objective of the US LCI database project is to make the data available for a variety of intended user groups in a manner that will ensure as informed and time- and cost-efficient use as possible (see Section 2.1). Data will therefore be documented in accordance with the ISO 14048 documentation format, and presented on a fully disaggregated unit process basis.

Proprietary information provided on a confidential basis by individual companies or plants will have to be protected. This need will automatically be met in most cases by the normal process of combining company-specific unit process data across an industry, and reporting aggregate data for each unit process ("horizontal aggregation"). In some instances, for example if the sample of reporting companies is small, it may be necessary to aggregate data for two or more unit processes which occur in series before publishing the results in the database ("vertical aggregation"). In extreme cases (e.g., when there is only one manufacturer of a product and that manufacturer provides data under a confidentiality agreement), it may be necessary to aggregate data for one product with that for another similar product, thereby creating a combined product class.

Because of the losses of information, transparency, and utility, vertical aggregation should only be used when it is required to avoid disclosure of competition-sensitive information.

When aggregation is necessary to protect any proprietary manufacturer information, roll-up procedures must be clearly explained.

The project will also make unit process "tree" models available to users so that individual unit process modules can be clearly understood within the context of broader product process trees.

Transparency and longevity of the data will be further ensured by maintaining a confidentially held copy of the original data that were aggregated to produce the publicly released data. In this way, it will always remain possible to re-evaluate and re-compute the modules in the event that new guidance arises for procedures such as allocation, or questions arise as to the basis for the aggregated data.

12 TRANSPARENCY

Transparency requires open access to all pertinent "data about the data", or meta-data. Central transparency objectives of the US LCI database project are to develop and publish LCI data in a form that provides enough information about the nature and sources of the data so that users and third parties can do the following for each data item:

- know the source(s) and age of the data;
- know how well the data represents an industry or process;
- understand how the underlying calculations were made;
- evaluate the appropriateness of the data for the user's intended application;
- validate the results through testing and cross-checking of data and modeling; and, ultimately,
- make an informed determination concerning the extent to which they can rely on the data and conclusions drawn from it.

Adequacy of Documentation will be ensured through the following means:

- open publication of this research protocol governing how the databases are to be developed;
- adherence to guidance on the documentation from ISO 14040 and 14041; and
- use of the ISO 14048 Technical Specification "LCA Data Documentation Format" in documenting the unit process data and system data.

All data developed in the US LCI database project will be communicated to third parties (i.e., other than the commissioner of the study and the LCA practitioner). Data developers must therefore adhere to all applicable elements of Section 6 of ISO 14040, which specifies the required contents for such third-party reports. Life cycle impact analysis is an example of an element of ISO 14040 that is not applicable since it is outside the scope of this project. The same is true of documentation related to life cycle interpretation, although in that case documentation to meet the requirements of other elements should be sufficient to enable users to assess the quality of the data. Key elements of ISO 14041, which sets out more specific reporting requirements, are listed below, with an indication of the approach to be taken in project documentation.

Given the public nature of the US LCI database and its availability through the web site, it will be essential to have a formal process for changing data sets and for others to comment on, or challenge, data. This matter is outside the scope of this protocol, but must certainly be the subject of clear guidelines in the data user's guide and be highlighted on the web site.

Aspect for inclusion per ISO 14041	Approach to be taken
Section 5.3.3 on initial system boundaries states that "the system *should* be described in sufficient detail and clarity to allow another practitioner to duplicate the inventory analysis."	Systems *shall* be described in sufficient detail
Section 5.3.5, on criteria for initial inclusion of inputs and outputs: "The criteria and the assumptions on which they are established *shall* be clearly described. The potential effect of the criteria selected on the outcome of the study *shall* also be assessed and described in the final report." And, "Where the study is intended to support a comparative assertion made to the public, the final sensitivity analysis of the inputs and outputs data *shall* include the mass, energy and environmental relevance criteria."	Full compliance in the context of the unit process under study
Section 6.3, on data collection: "A description of each unit process *shall* be recorded. This involves the quantitative and qualitative description of the inputs and outputs needed to determine where the process starts and ends, and the function of the unit process. Where the unit process has multiple inputs… or multiple outputs, data relevant for allocation procedures *shall* be documented and recorded."	Full compliance
Section 6.4.5, on refining the system boundaries with sensitivity analysis to test significance: "The results of this refining process and the sensitivity analysis *shall* be documented."	Full compliance where relevant
Section 6.5.2, on allocation principles: "The allocation procedure used for each unit process of which the inputs and outputs are allocated *shall* be documented and justified."	Full compliance

13 DATA QUALITY AND UNCERTAINTY

The information about, and consequences of, uncertainty and data quality in life cycle inventory analysis operate at three levels:

1. PROCESS LEVEL: First, there is the quality of, and uncertainty in, the data at the level of individual unit processes.
2. SYSTEM LEVEL: Second, there are the total uncertainties in "rolled-up", cradle-to-gate aggregated life cycle inventory results for a product or material; and
3. APPLICATION LEVEL: Third, in a given application, there is the additional layer of uncertainties (and their net effects) arising through mismatches between the subjects of the original LCI data and the actual unit processes or systems that they are being used to model.

The US LCI database project will be consistent with ISO 14041 Section 5.3.6. It must also take into account the need to protect competition-sensitive information about the production methods or economics of any single company. In most cases this will be addressed by combining company-specific data across an industry, and reporting aggregate data for each unit process.

The data formatting guidelines in ISO 14048 specify the following minimum data quality documentation requirements for each unit process. The required documentation will capture the information needed to support subsequent analysis of the aggregated uncertainty of cradle-to-gate data sets. The documentation will also allow users to understand what the data represent and assess how well this correlates with the intended use of the data.

The documentation requirements are as follows:

1. For primary and secondary data:
   a. Identification of age, source, method of collection (e.g., measured, estimated from process engineering, etc.)
   b. Identification of how representative the data are of an industry or process group (e.g., the percentage of total production represented by the sampled plants, rather than just "4 plants out of 20"). Also, documentation should make clear the nature of technology sampled (i.e., average, best-available, etc.) and the aggregation method used to produce the industry average data required in the data modules.
2. Documentation of the methods used to estimate missing data or to justify excluding ancillary materials or missing data from the analysis. If sensitivity analysis is used, its results should be summarized; if surrogate data are used from other processes, these processes and their data sources should be clearly identified.
3. Description of the aggregation approach used to protect competition-sensitive company-specific information (e.g., use of weighted averages, data for one product rolled in with that of a similar product, etc.).
4. Explanation of all assumptions and calculation methods in sufficient detail that a reader or reviewer can duplicate basic calculations or evaluate sensitivity of results to key assumptions or methodological choices, e.g., for co-product allocation.

For each unit process, the following uncertainty documentation shall also be provided:

1. For primary data: All available information characterizing the uncertainty of the data, including but not limited to sample size, mean, minimum and maximum values, standard deviation, suggested best representative distribution shape, etc. OR,
   if the sample size is small, an estimate of the uncertainty of the data (e.g., +/- 20%) based on sources or expert judgment, along with documentation of who provided the estimate and on what basis.
2. For secondary data: All information available from the source that characterized the uncertainty of the data such as the information described above.

14 CO-PRODUCT ALLOCATION

There are cases where a unit process produces multiple outputs. The problem for LCI data is to properly allocate elementary flows for that unit process to the product of interest. Allocation procedures for this project will be in accordance with ISO 14041:1998(E), section 6.5.3, and 14049:2000(E), section 7.2.

ISO sets out a three-step hierarchy for allocation.

Step 1 is to *avoid* allocation altogether. When the "unit process" actually consists of multiple parallel sub-process chains, then using greater modeling detail avoids the need for allocation. Failing this, the second avoidance approach is to expand the system model, effectively giving credit to the primary or "determining" product for other production displaced, or avoided, by the co-products.

Step 2 is to study the system to determine how the burdens (i.e., the process inputs and releases) are changed by shifts in the co-product shares, and to then allocate the process burdens based on direct *physical relationships*. Such study might elucidate a simple physical basis for allocation, such as surface area explaining paint usage and emissions. Alternatively, regression analysis may provide coefficients estimating burden per unit of each output. Either way, the resulting Step 2 allocation basis *must* (i.e., "shall") reflect the "underlying physical relationships" between the burdens and the output shares. The result of such system study or regression analysis *may* turn out to be equivalent to mass-based apportioning of burdens, but ISO explicitly states that Step 2 is *not* the same as *a priori* apportioning of burdens to co-products according to their mass or molar shares.

Step 3 is necessary if Steps 1 and 2 cannot be done. Step 3 is to use some *other relationship* between the burdens and the product output as a basis for allocation. Here, use of the economic value shares among the product outputs is recommended where feasible.

In summary, allocation practice should be carried out with the following guidelines:

1. Be fully consistent with the ISO hierarchy among methods: avoid, use physical relationships, use other cause-approximating relationships (e.g., value);
2. Be fully consistent with the ISO requirement to document the reasons for every allocation method choice; and
3. Publish the data with enough transparency to enable interested LCA practitioners to conduct their own tests of the sensitivity of results to the selection of different allocation approaches.

As discussed in the Phase I final report, an early Phase II task should be the development of meta-data and more specific procedural guidelines for both system expansion and allocation by economic value. The data and guidelines should then be made available as an annex to this protocol or be used to further elaborate this Section.

15 ALLOCATION FOR REUSE AND RECYCLING

The approach to modeling unit processes associated with waste management and recycling in the US LCI database project shall fully conform to the ISO 14041 standard, also illustrated in ISO Technical Report 14049 ("Examples of application of ISO 14041"). In particular, the approaches to handling allocation associated with recycling will follow the methods outlined in section 6.5.4 of ISO 14041, Allocation Procedures for Reuse and Recycling.

The standards cited above pertain to full attributional (as opposed to consequential) life cycle assessments, and to system models that include either a closed-loop chain of processes or an open-loop system requiring estimation of the number of total life cycles that will occur after the primary product usage phase. In contrast, the US LCI database project is providing unit process LCI results for systems that do not include the usage phase of product lives. As a result, the database project will not include entire closed loops around the usage phase, with post-consumer resource recovery, processing, and subsequent displacement of virgin material (as described, for example, in Figures 14-17 of ISO 14049). Instead, the database must do the following:

- provide data that can be used as part of total life cycle assessment models that are constructed in an ISO-compliant manner;
- capture, and provide users with, information about the shares of recycled content used as inputs to production in current practice;
- enable users to analyze life cycle scenarios with various levels of post-consumer recovery and recycling; and
- enable users to analyze product systems involving alternative scenarios regarding shares of recycled content used as inputs to production.

15.1 Open loop recycling

ISO 14041 specifies that changes in the inherent properties of materials shall be taken into account, and that open loop allocation procedures and modeling be applied when recycled material undergoes changes to its inherent properties, as shown in Figure 4 of 14041. Specifically, ISO calls for open loop modeling of the recycling of property-changing materials, and closed-loop allocation procedures for other materials whose inherent properties are not changed by recycling, whether they are in fact recycled in the same or a different product system.

For materials whose inherent properties change as a result of recycling, the US LCI database shall model the input of recovered materials to processes as follows.

1) The original production of the recovered product shall be modeled using LCI data for a representative or typical product actually found entering the material recovery stream of interest, based on current US conditions.
2) The burden of the initial production of the recovered product (i.e., virgin content) shall be allocated among its initial and current uses. Where evidence supports the conclusion that there is already a high proportion of recycled content in the

recovered material, the allocation factor should reflect the average number of previous uses.

3) Where reliable data does not exist to support such a calculation, the analysis will assume there has been no previous recycling and half the burdens of the initial production shall be allocated to the material entering the reprocessing stream.

   In 2) or 3), above, use-phase-related burdens in the initial or subsequent product lives should not be allocated to the post-consumer material. However, the full system of processes required for recovery and recycling shall be included in the model for the recovered material, with 100% of the burdens assigned to the current use.

4) Any recycling or potential for recycling beyond the unit processes under study in the project will be the responsibility of users of the US LCI database. Suitable guidelines will be provided in the separate data user's guide.

15.2 Closed Loop Recycling

For recovered materials whose inherent properties do not change as a result of recycling, the US LCI database models shall show input of the required amount of recovered material, free of any burdens associated with its original production, into the full series of processes required to collect and reprocess the material for input into manufacturing. If recovered material goes back into manufacture of the same product, it will be assumed that the inherent properties have not changed.

Again, the user's guide will provide instruction on the modeling of recovered materials in this category through subsequent post-consumer recycling phases.

16 SENSITIVITY ANALYSIS

Sensitivity analysis is used during database development, and it may also be undertaken later by individual users of the data. For example, sensitivity analysis may be used in the following instances:

- during database development to determine whether results are sensitive to missing data, based on tests with proxy data; and
- during data use to analyze the effect of different methods for co-product allocation, or to compare specific situations to industry averages.

One of the principal advantages of collecting, reporting, and documenting data at the unit process level is that it enables users to undertake this latter form of sensitivity analysis.

When setting the input boundaries for a system and considering the exclusion of materials that contribute small amounts to the total mass of the system, or exclusion of missing data, sensitivity analysis shall be employed to evaluate the environmental significance of the potentially excluded data. For these cases, surrogate or estimated data can be used to represent these materials in an initial analysis of the system, and the potential contributions to system totals from these materials can be evaluated. The cut-off criteria for excluding materials from the system boundaries were defined in Section 7.

The data documentation required in Section 12will provide information on the data quality, modeling assumptions and methodological choices used to develop each unit process data set. This documentation should be sufficient to allow the user to understand key assumptions that were made, and to undertake sensitivity analyses of influential assumptions. For example, a user may wish to examine the effect on results of various methodological approaches for co-product allocation in a unit process. The unit process level of data detail will also enable many other forms of user-based sensitivity analysis, such as evaluating the influence of use of a specific supplier (for which the user has data) compared with the industry average.

17 CRITICAL REVIEW

It is important that unit process data be evaluated by internal and external experts, and compared with available published data, to ensure uniformity of approach and consistency with international work. Given a reasonable allowance for small errors and variations of method, any data that appears inconsistent with published data should be referred to an appropriately constituted review panel for judgment. However, this kind of critical review will not be the direct responsibility of the data developers working on individual US LCI database modules. Critical review will be the responsibility of the agency making the data publicly available, and a separate review protocol should be issued by that agency.

Appendix A — Conversion Factors

VOLUME AND MASS

VOLUME	cubic inch	ml	liters	U.S. fl. oz.	U.S. gallons*	U.S. barrels	cubic feet
cubic inch	x	16.387	0.0164	0.554	$4.329x10^{-3}$	$1.374x10^{-4}$	$5.787x10^{-4}$
ml	0.0610	x	0.001	0.03381	$2.642x10^{-4}$	$8.387x10^{-6}$	$3.532x10^{-5}$
liters	61.024	1000	x	33.815	0.264	$8.387x10^{-3}$	0.0353
U.S. fl. oz.	1.805	29.573	0.0296	x	$7.812x10^{-3}$	$2.48x10^{-4}$	$1.044x10^{-3}$
U.S. gallons*	231	3785	3.785	128	x	0.0317	0.134
U.S. barrels	7276.5	$1.192x10^{5}$	119.237	4032.0	31.5	x	4.21
cubic feet	1728	$2.832x10^{4}$	28.316	957.568	7.481	0.2374	x

MASS	grams	kilograms	ounces	pounds	grains	tons	milligrams
grams	x	0.001	$3.527x10^{-2}$	$2.205x10^{-3}$	15.432	$1.102x10^{-6}$	1000
kilograms	1000	x	35.274	2.205	15432	$1.102x10^{-3}$	$1x10^{6}$
ounces	28.350	0.28	x	0.0625	437.5	$3.125x10^{-5}$	$2.835x10^{4}$
pounds	453.59	0.453	16.0	x	7000	$5.0x10^{-4}$	$4.536x10^{5}$
grains	0.065	$6.480x10^{-5}$	$2.286x10^{-3}$	$1.429x10^{-4}$	x	$7.142x10^{-8}$	64.799
tons	$9.072x10^{5}$	907.19	$3.200x10^{4}$	2000	$1.4x10^{7}$	x	$9.072x10^{8}$
milligrams	0.001	$1x10^{-4}$	$3.527x10^{-5}$	$2.205x10^{-6}$	0.0154	$1.102x10^{-9}$	x

***NOTE:** U.S. gallon = 0.80 Imperial gallons (Source: U.S National Technical Information Services)

To convert from	to	multiply by
Grams / cu ft	Milligrams / cu m	$35.315x 10^{3}$
Pounds / 1000 cu ft	Milligrams / cu m	16.018×10^{3}
Barrels Imp (petroleum)	liters	158.98
Btu's	joules	1054
Cubic yards	liters	764.534
Feet	meters	0.305
Gallons (British)	liters	4.546
Gallons (U. S.)	liters	3.785
Inches (in)	meters	0.025
Kilowatt - hours (kWh)	Mega joules	3.6
Miles (statute)	kilometers	1.609
Ounces (avdp)	kilograms	0.028
Pounds	kilograms	0.454
Square feet	square meters	0.093
Tons (short)	kilograms	907.185
Watts	joules / sec	1
Yards	meters	0.914
Pounds	metric ton	0.0004
Acres	hectares	0.405
Square miles	hectares	259
Cubic feet (ft^3)	cubic meters (m^3)	0.028
Cubic inches (in^3)	cubic centimeters (cm^3)	16.393
Watt - sec	joule	1
Calories (cal)	joules	4.105
Gram - calorie	joules	4.184
Watt - years	joules	3.15×10^{7}

Sources: 1. Starr, C. *Energy & Power*. Scientific American , 1971; 2. Handbook of Industrial Energy Analysis**.**